



# Development of techniques to investigate sonoluminescence as a source of energy harvesting

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# Outline

- Introduction
- Generation of Sonoluminescence
  - Apparatus
  - Imaging
- Indications of High Temperature
  - Platinum Films
  - Palladium-Chromium Films
- Energy Harvesting
  - Fusion Claims
  - Scintillator Detectors
  - Energy Harvesting Concept
- Summary



“Star in a Jar”  
– *W. Moss, LLNL*



# NASA's Mission: To pioneer the future in space exploration, scientific discovery, and aeronautics research

*"Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems."*

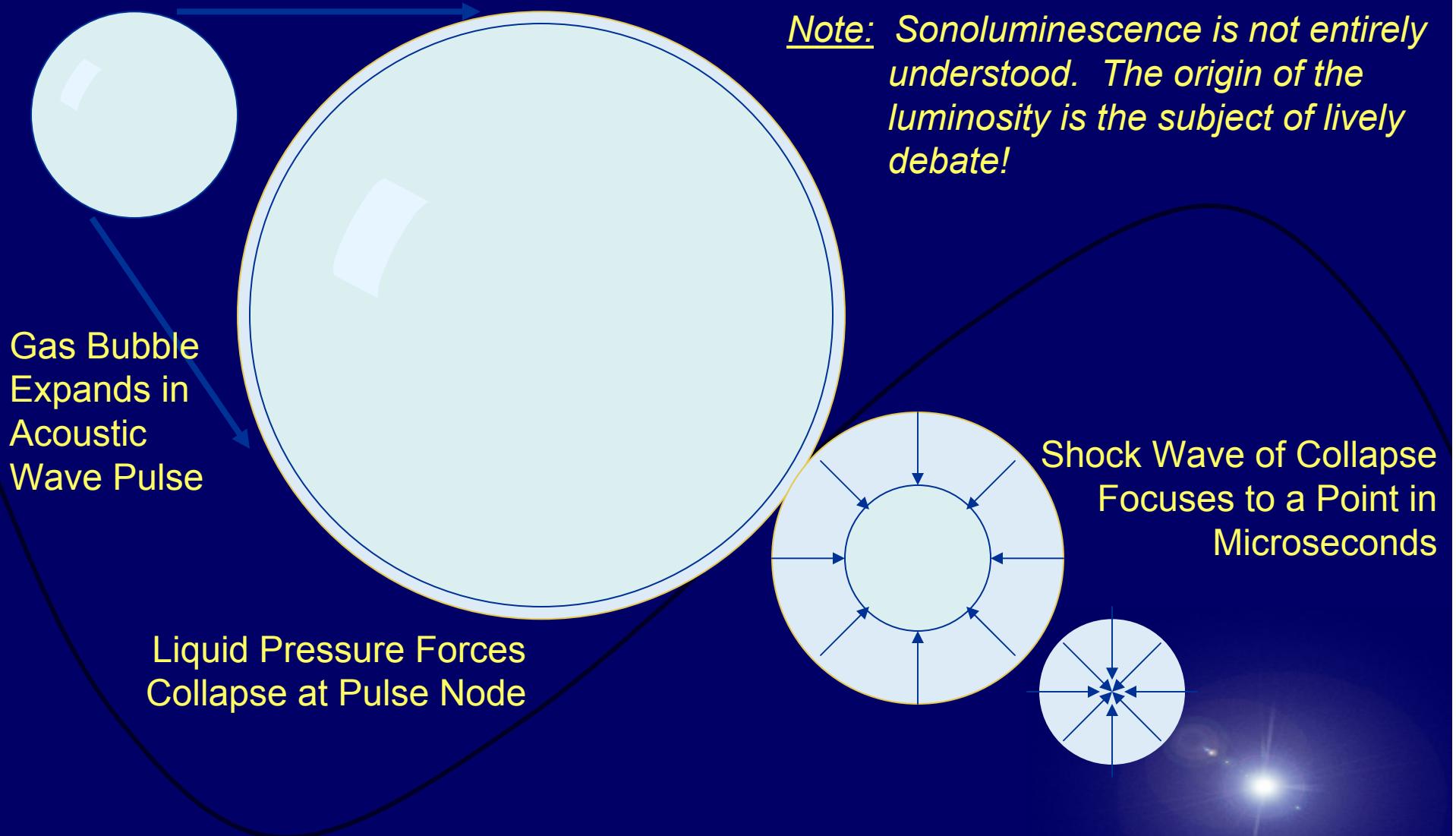
*– NASA 2006 Strategic Plan*



*Develop the innovative technologies, knowledge, and infrastructures both to explore and support decisions about the destinations for human exploration*

*– Vision for Space Exploration*

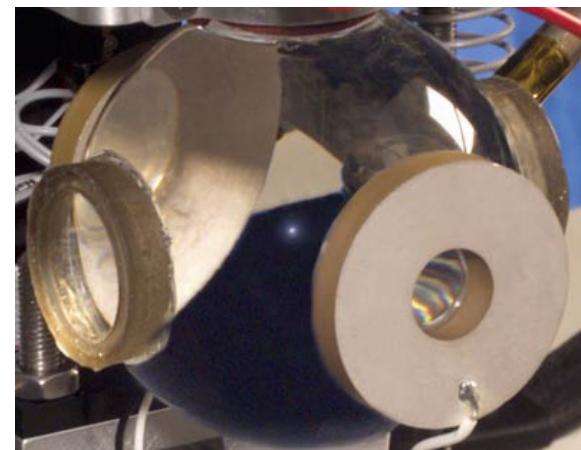
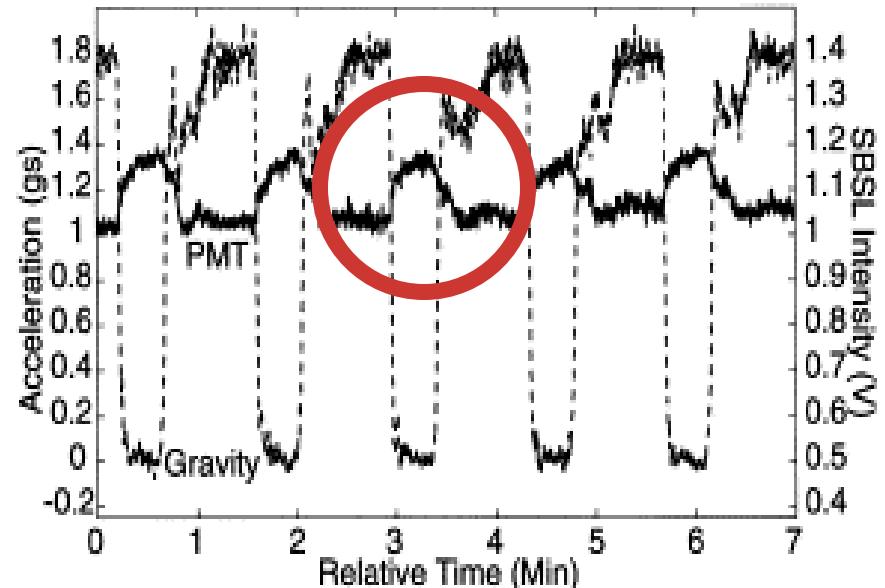
# The Sonoluminescence Process





## Sonoluminescence in Microgravity

- KC-135 Flight in 1998 by University of Washington
- SBSL promptly brightened 20% and continued brightening under microgravity conditions
- ISS experiment was scheduled for launch April 2005
- Flight hardware under development in 2003
- Experiment cancelled in the redirection of space exploration efforts





# NanoStar: Sonoluminescence

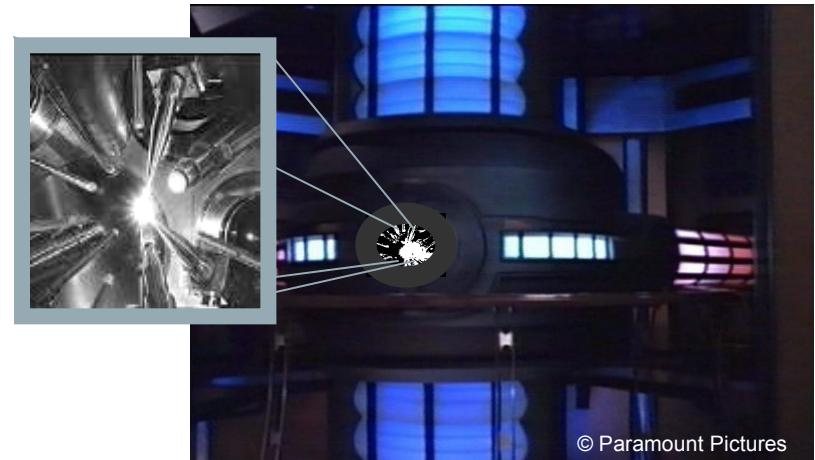
Gus Fralick (PI - RIS), John Wrbanek (RIS), Susan Wrbanek (RIO)



From a “Star in a Jar”...

- **Sonoluminescence:** The phenomenon in which acoustic energy is concentrated into collapsing bubbles that emit picosecond pulses of broadband light.
- Calculations indicate that peak temperatures inside the SL bubbles may exceed 12 million K, that peak pressures may reach 100 million atmospheres, could initiate D-D fusion.
- Harnessing the high energy release would lead to the development of revolutionary propulsion and power systems.
- Developing instrumentation and measurement techniques to investigate power generation using sonoluminescence.
- Initially determine whether there is any difference in the emission spectrum of radiation from bubbles in heavy water ( $D_2O$ ) and light water ( $H_2O$ ).

- **Advancing the Existing State of the Art**
- The claims and theories are being examined predict a net gain of power resulting from atomic interactions at the high temperatures and pressures present in SL.
- SL-based power generation has been only recently reported in the main-stream academic press (*Science*, 8 Mar 02).
- The development of measurement techniques to verify and further develop this technology is a necessity.



© Paramount Pictures

...to the Future?



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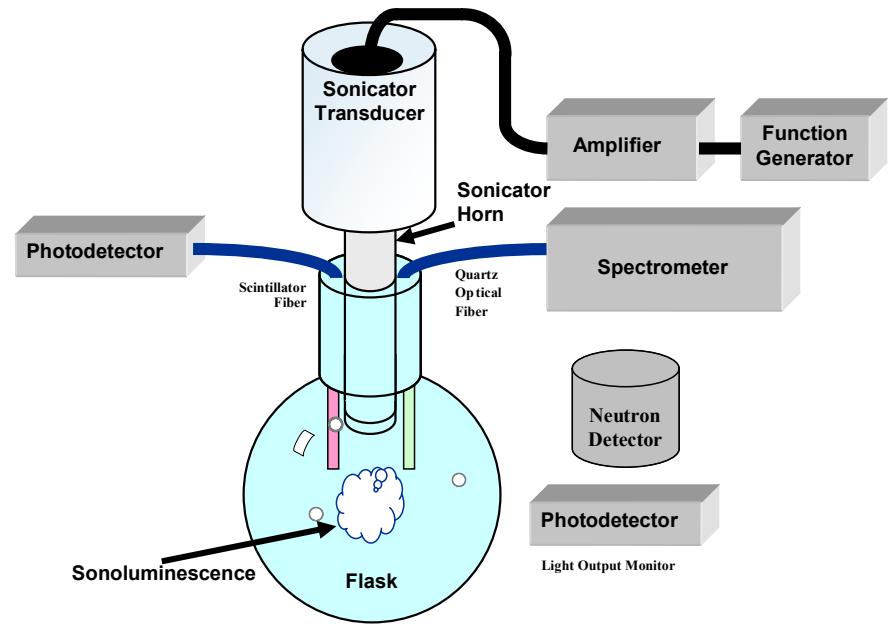
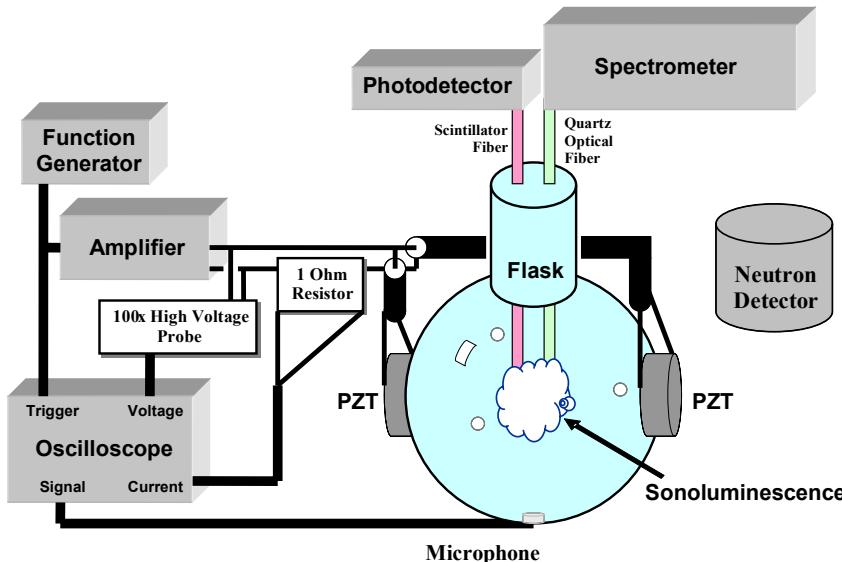
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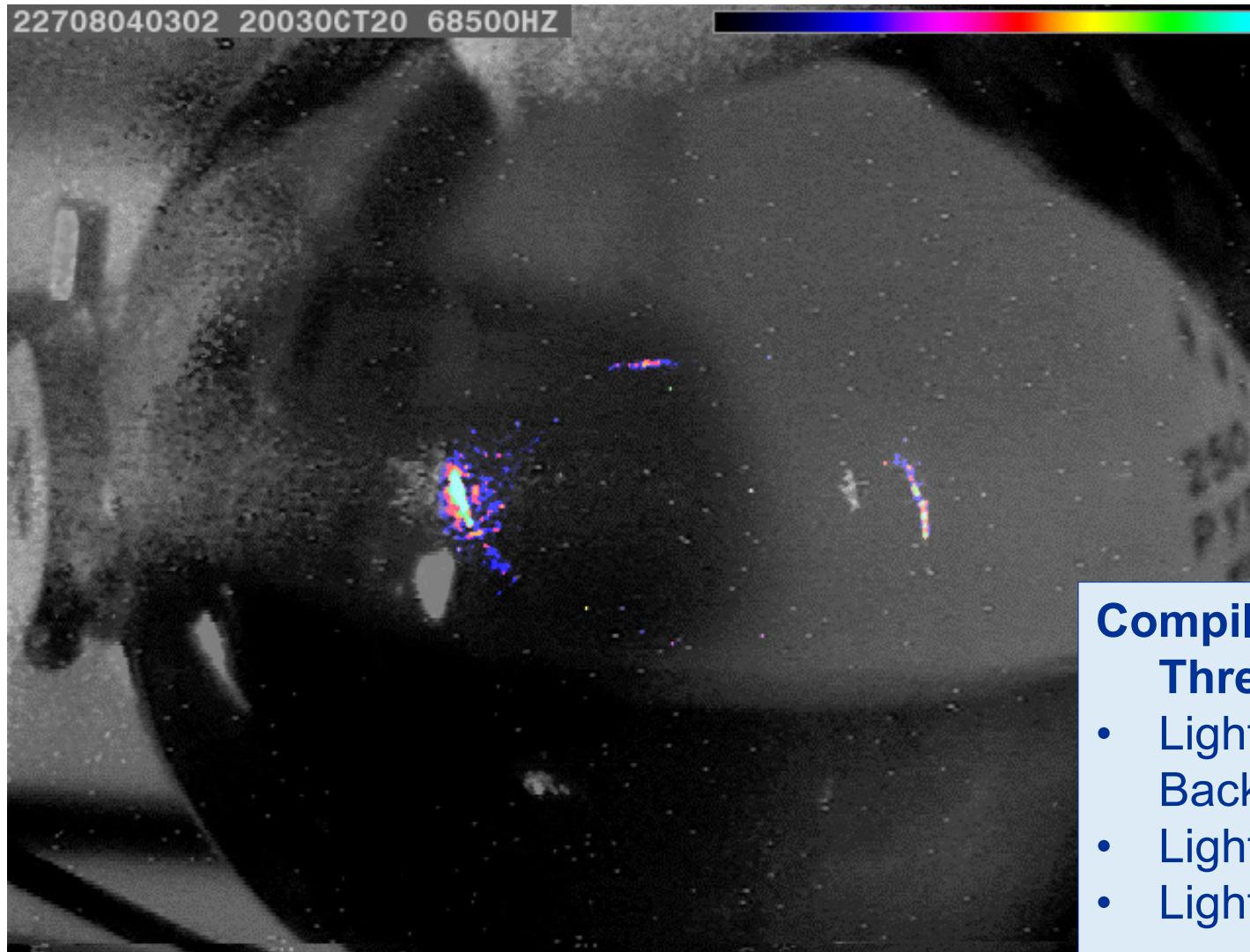
# Apparatus



- Ultrasonic transducer induces cavitation in a test cell
- Piezoelectric amplifier drives transducer from signal generator
- Two types of transducer setups
  - Resonating Test Cell
  - “Sonicator” Cell Disruptor in Flask or Beaker
- Photodetectors, Spectrometers, Neutron Detectors can be used
  - Monitor with Lights Out!



# Multi-Bubble Sonoluminescence (MBSL) Ring Imaged with Low Lux Video Camera

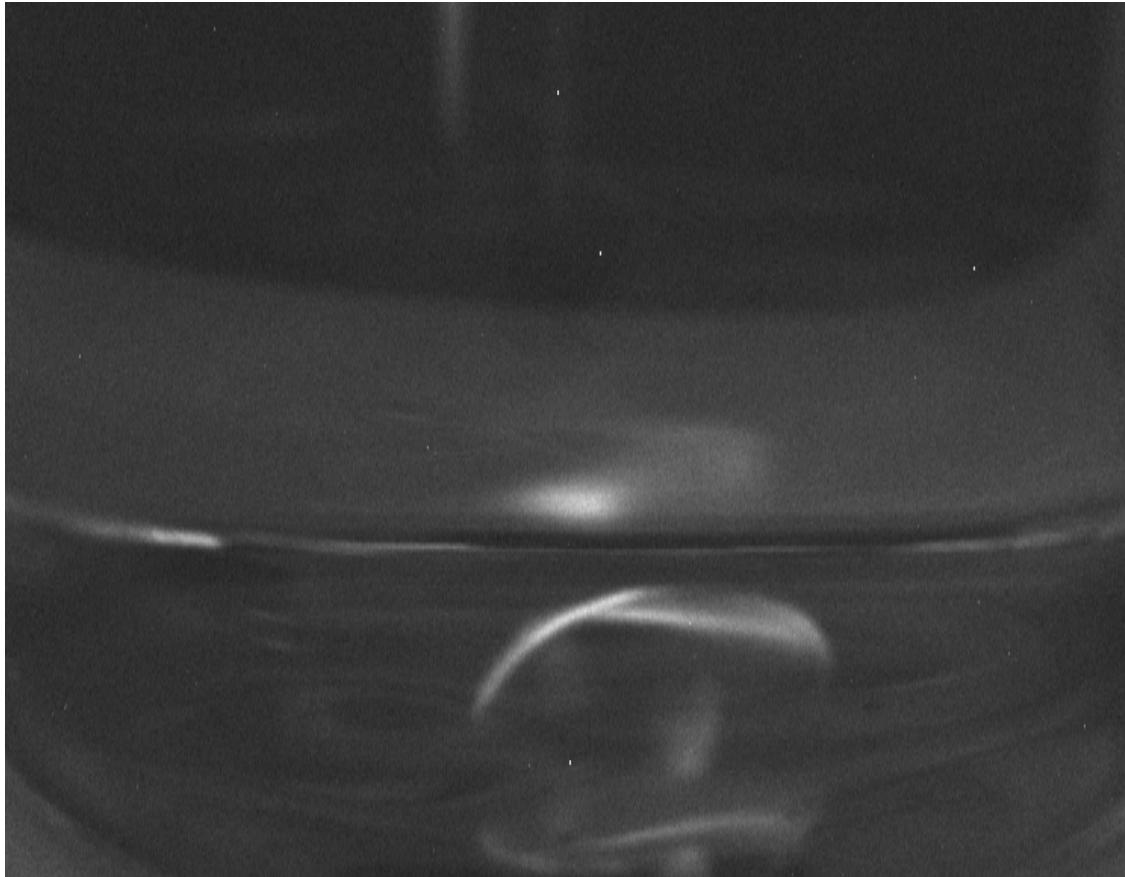


**Compilation of  
Three Images:**

- Lights Off  
Background
- Lights On Flask
- Lights Off MBSL



# Multi-Bubble Sonoluminescence (MBSL) Imaged using Astrophotography Camera

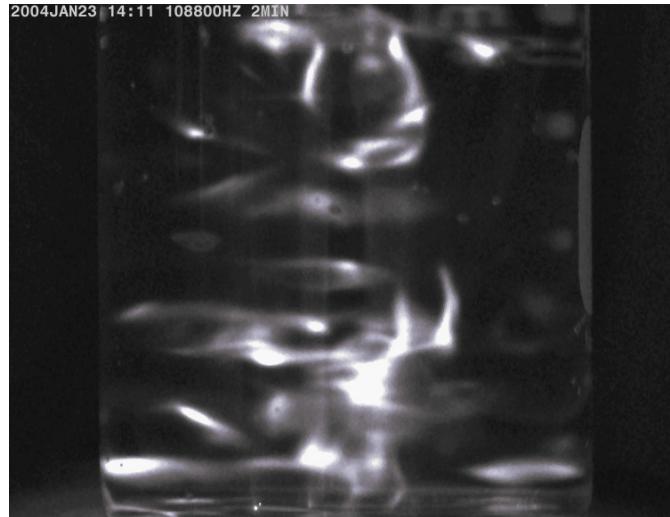


- Image quality allows better placement of instrumentation
- Improved image of MBSL over video camera
  - Enhanced contrast only

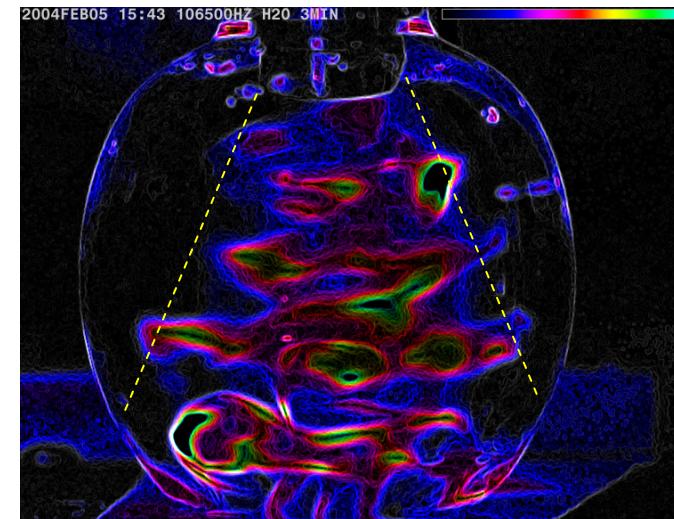
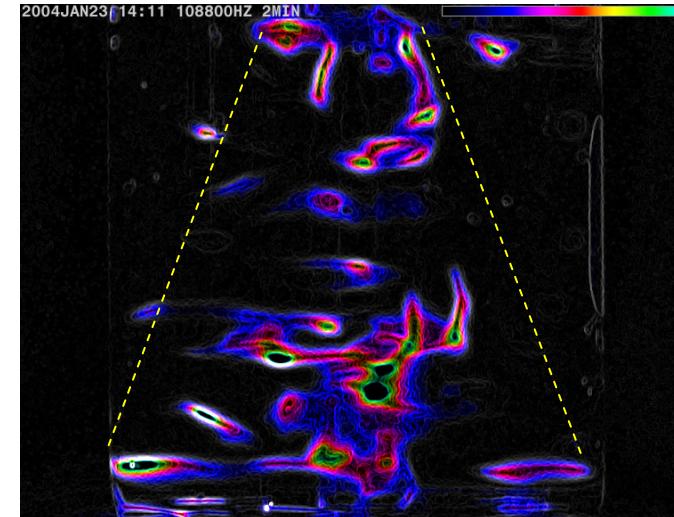
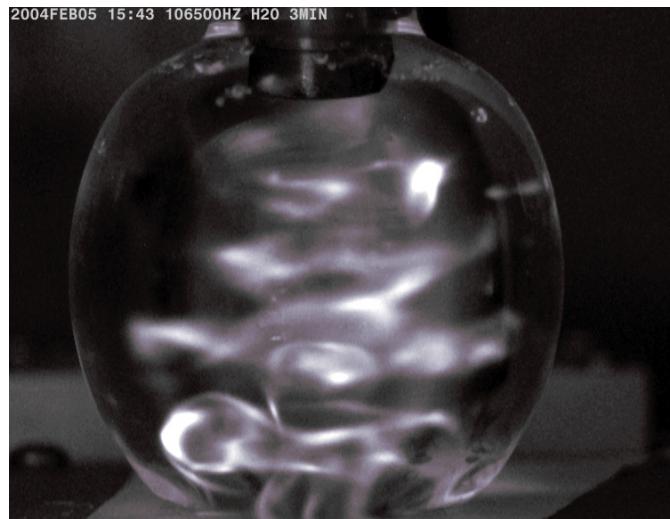


# MBSL using Sonicator Test Cell

- 100 ml Beaker



- 50 ml Quartz Flask

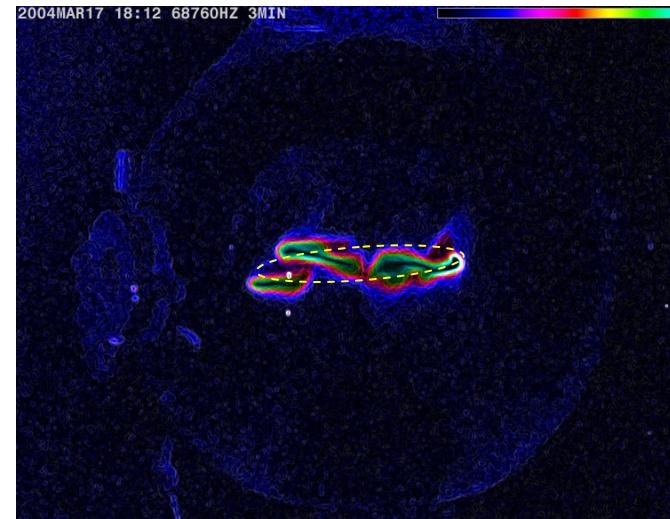


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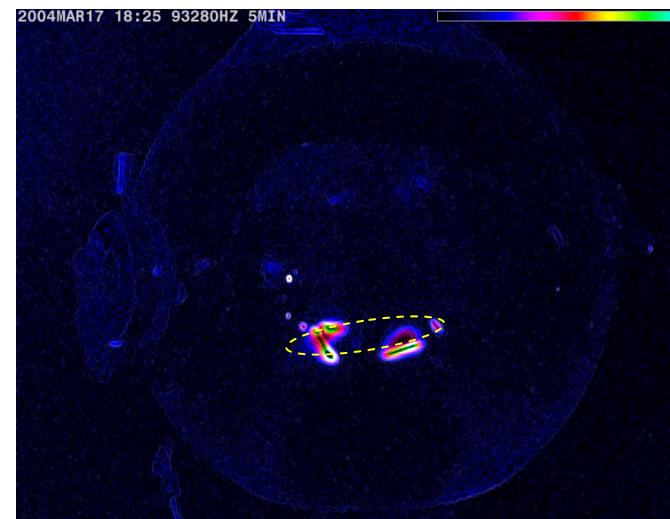


# MBSL in Resonating Test Cell

- 68.76 kHz



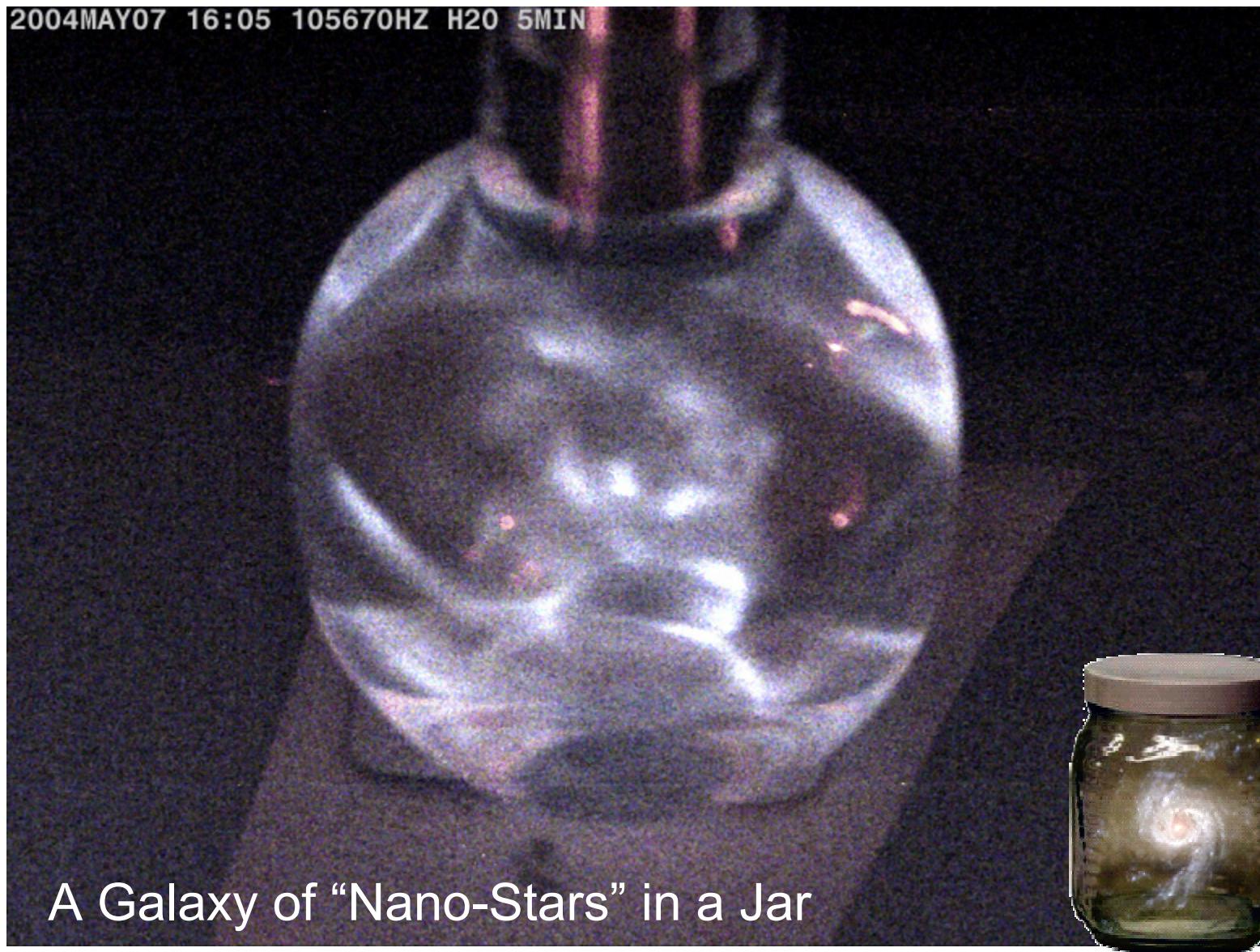
- 93.28 kHz



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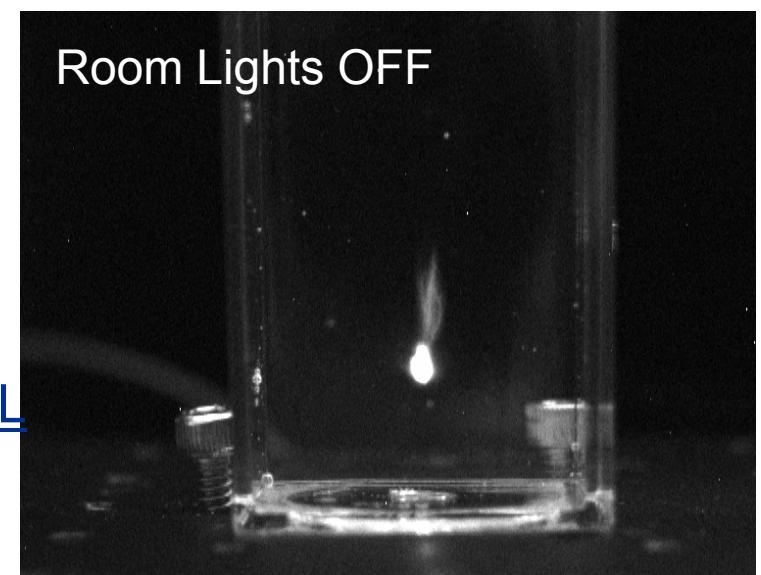
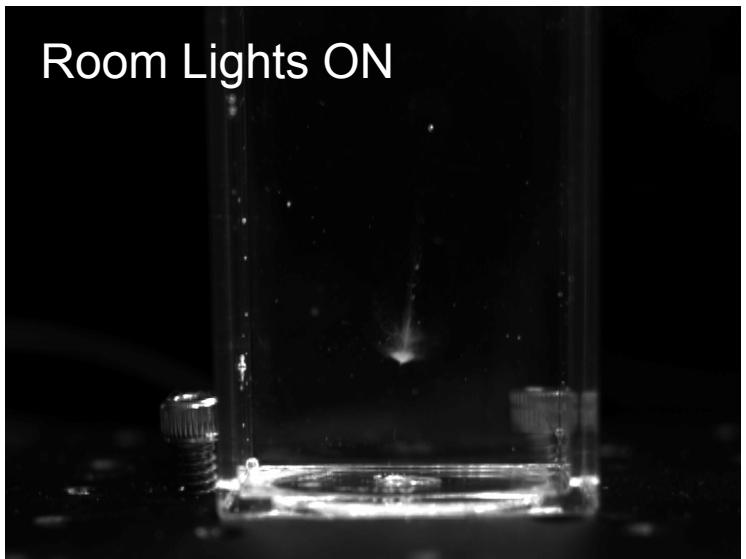
# True-Color MBSL in H<sub>2</sub>O





# Sonoluminescence in Solvents

- Empirical relationships correlate SL brightness with:
  - the liquid's viscosity,
  - surface tension,
  - inverse of the vapor pressure, or
  - a combination of properties
- Brighter sonoluminescence should be seen in the solvents with higher boiling points ( $>100^{\circ}\text{C}$ )
- Glycerin is an attractive solvent for use in sonoluminescence studies
  - Notoriously hydroscopic
  - Stabilizes as the 80% glycerin to 20% water mixture in air
  - Relatively safe and readily available
- Generated cavitation in Glycerin with a Sonicator setup corresponding to bright MBSL
  - Cavitation was particularly localized
  - Provides a promising target for spectroscopy and radiation studies





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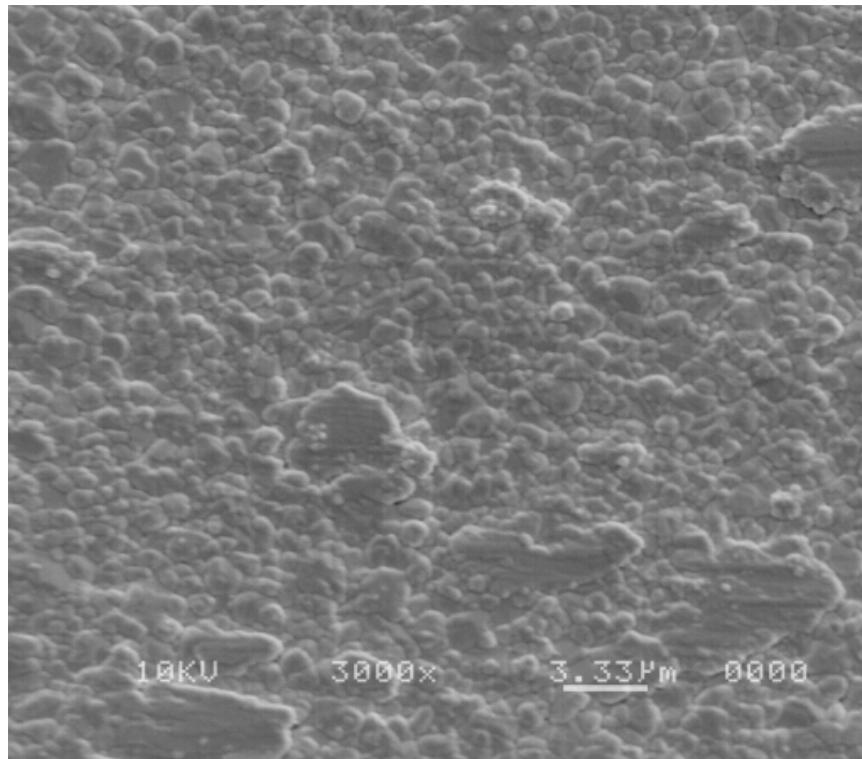


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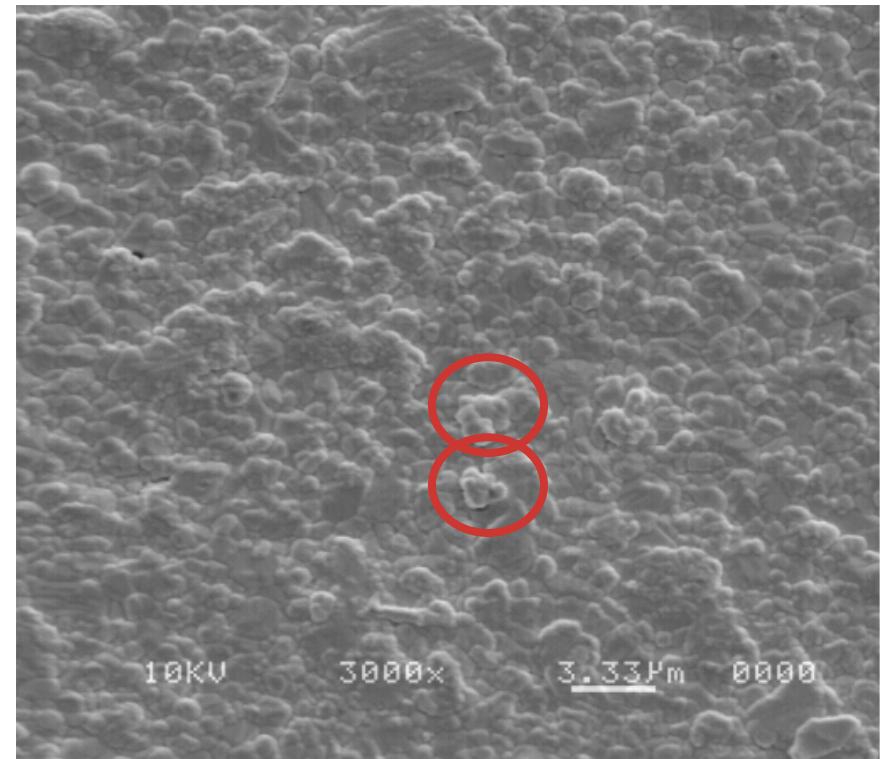


## Indications of High Temperature

- Modifications of films can indicate high temperature environments
  - Comparison can reveal temperature differences
- Initial Pt films on alumina exposed to MBSL in H<sub>2</sub>O and D<sub>2</sub>O showed little difference
  - Globules in D<sub>2</sub>O run? Not conclusive



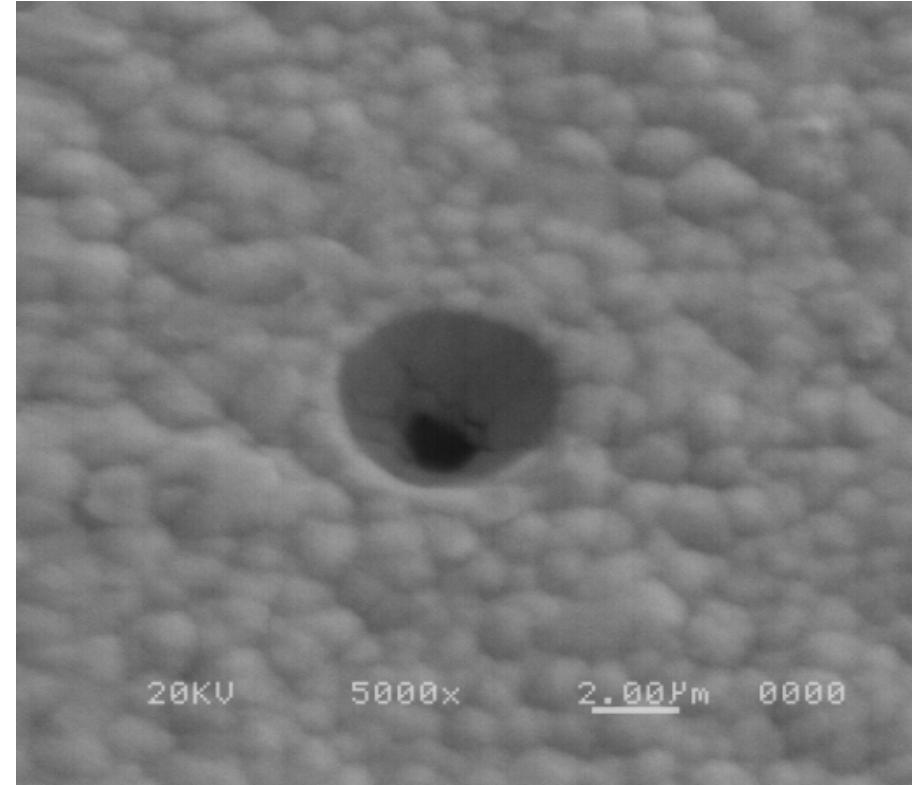
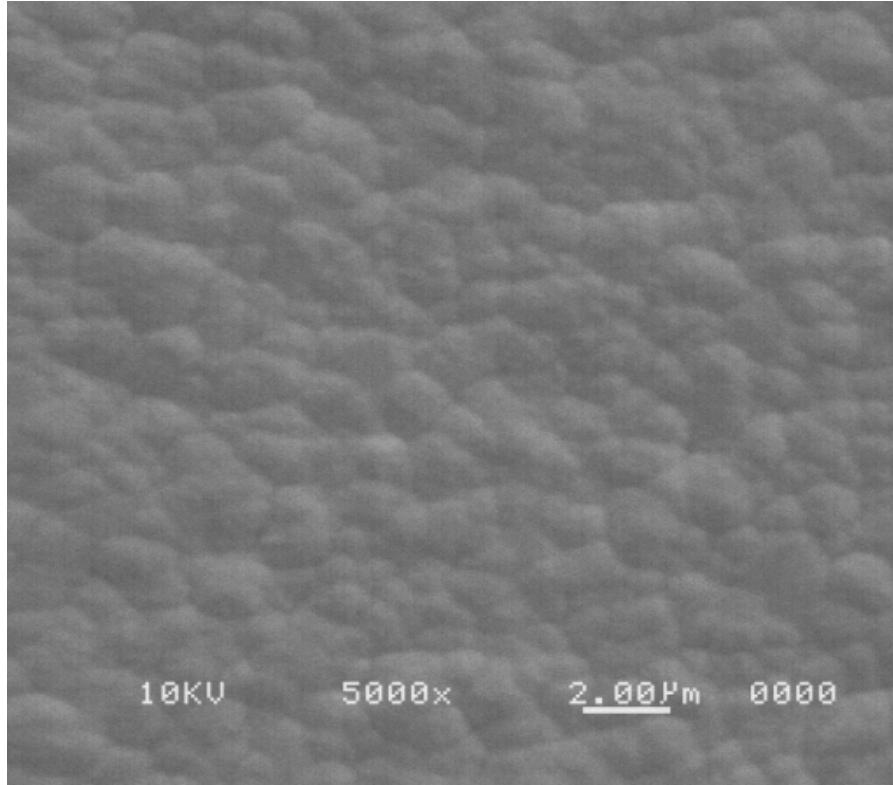
• Pt Film after exposure to MBSL in H<sub>2</sub>O



• Pt Film after exposure to MBSL in D<sub>2</sub>O



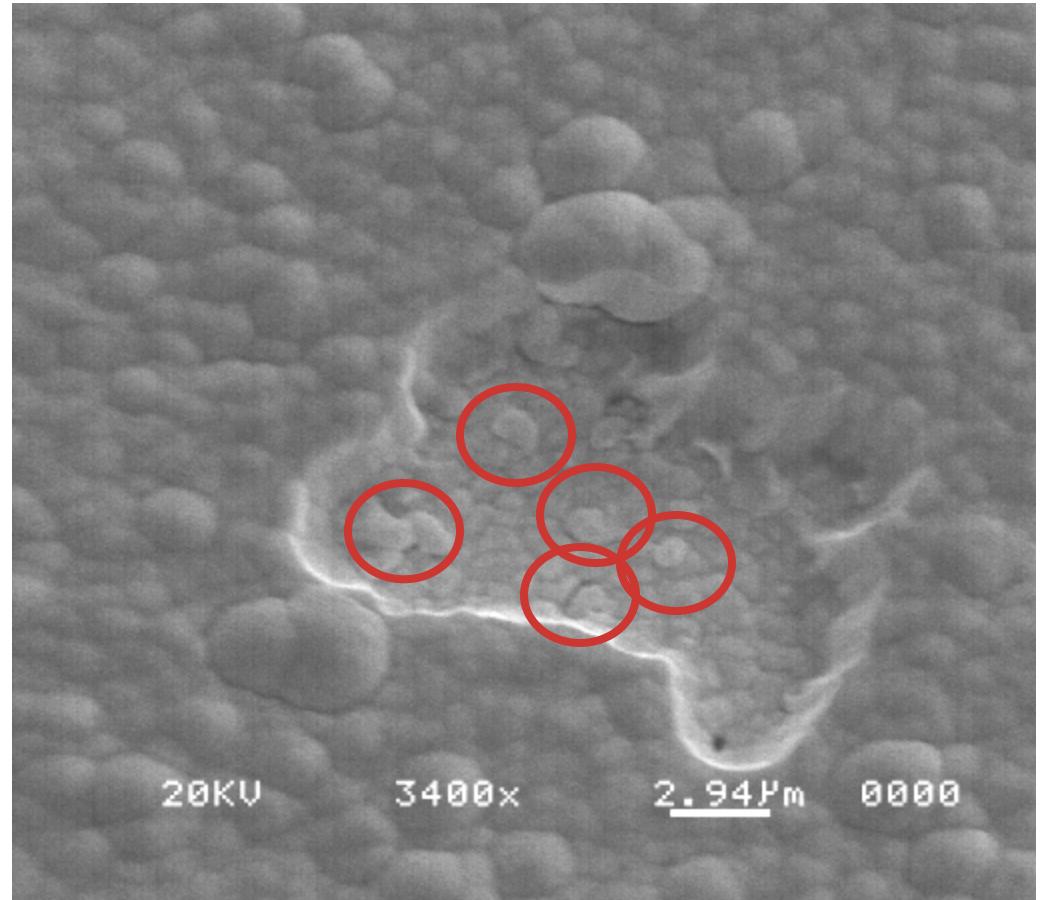
## PdCr Thin Films Over Pt RTD Traces on Alumina



- No Crater Formation seen after exposure to MBSL in H<sub>2</sub>O
  - Large Grain Failures usually seen in thin films due to CTE mismatches at high temperature (~1000°C)
- Crater Formation seen after exposure to MBSL in D<sub>2</sub>O

# PdCr Thin Films Over Pt RTD Traces on Alumina

- Large failure areas also seen in PdCr film over Pt exposed to MBSL in D<sub>2</sub>O
  - PdCr nodules appear on the bottom in failure areas
- Failures not seen in PdCr directly on alumina, or when exposed to MBSL in H<sub>2</sub>O runs





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# Sonoluminescence: Why do we care?

## Burning Coal:

- $C + O_2 \rightarrow CO_2$  (4 eV)

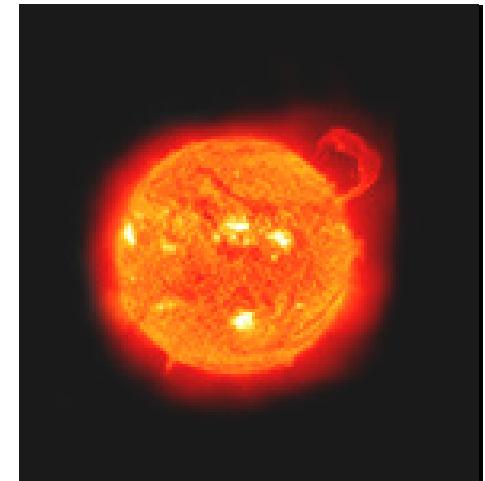


## Fission:

- $^{235}U + n \rightarrow ^{236}U$   
 $\rightarrow ^{141}Ba + ^{92}Kr + 3 \cdot n$  (170 MeV)

## Fusion Processes:

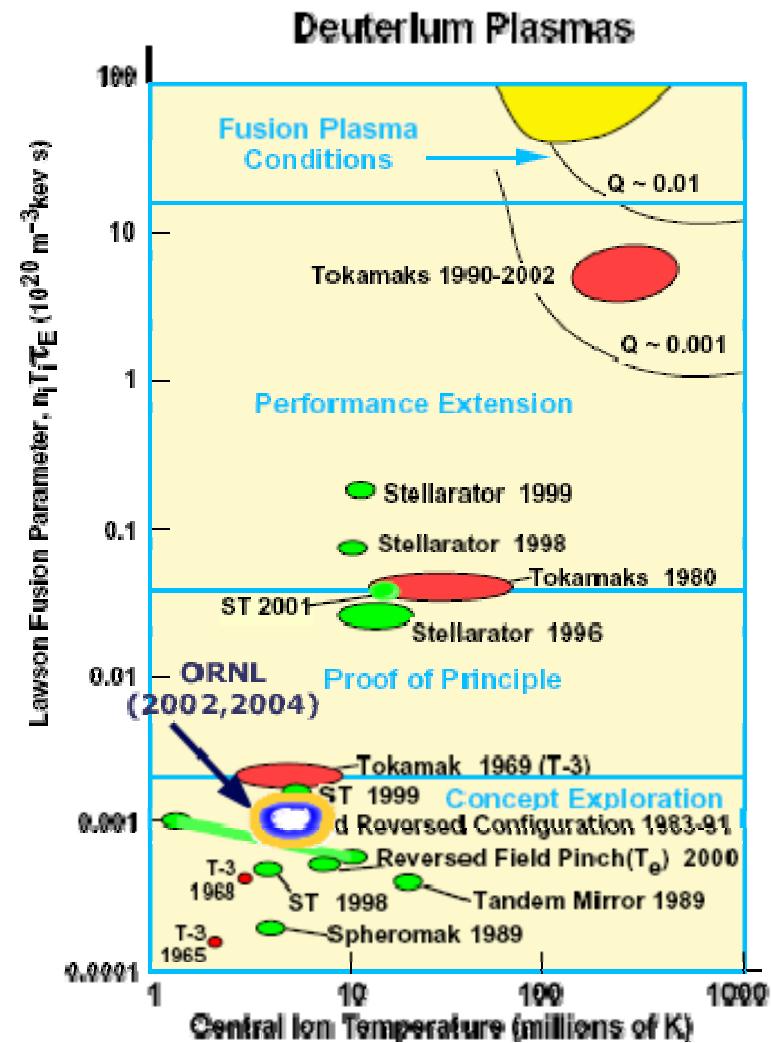
- $D + D \rightarrow T$  (1.01 MeV) + p (3.02 MeV)
- $D + D \rightarrow ^3He$  (0.82 MeV) + n (2.45 MeV)
- $D + D \rightarrow ^4He$  (73.7 keV) +  $\gamma$  (23.8 MeV)
- $D + ^3He \rightarrow ^4He$  (3.6 MeV) + p (14.7 MeV)
  - D =  $^2H$ , T =  $^3H$ ; D available from  $D_2O$ , “heavy” water and from deuterated solvents
  - At least 13% more productive per mass of fuel





# Lawson Diagram Metric to Track Fusion Development

- Conditions for D-D Fusion:
  - $T \geq \sim 4 \times 10^8$  K
  - $n\tau \geq 10^{16}$  s/cm<sup>3</sup> (Lawson Criterion)
- ORNL/Purdue claims that thermonuclear fusion using sonochemistry is possible (“Sonofusion” or “Bubble Fusion”)
  - Results supported by LeTourneau University
  - Discounted by UCLA
- The Lawson Criterion metric suggests that Sonofusion is at the point that Tokamaks were 35 years ago

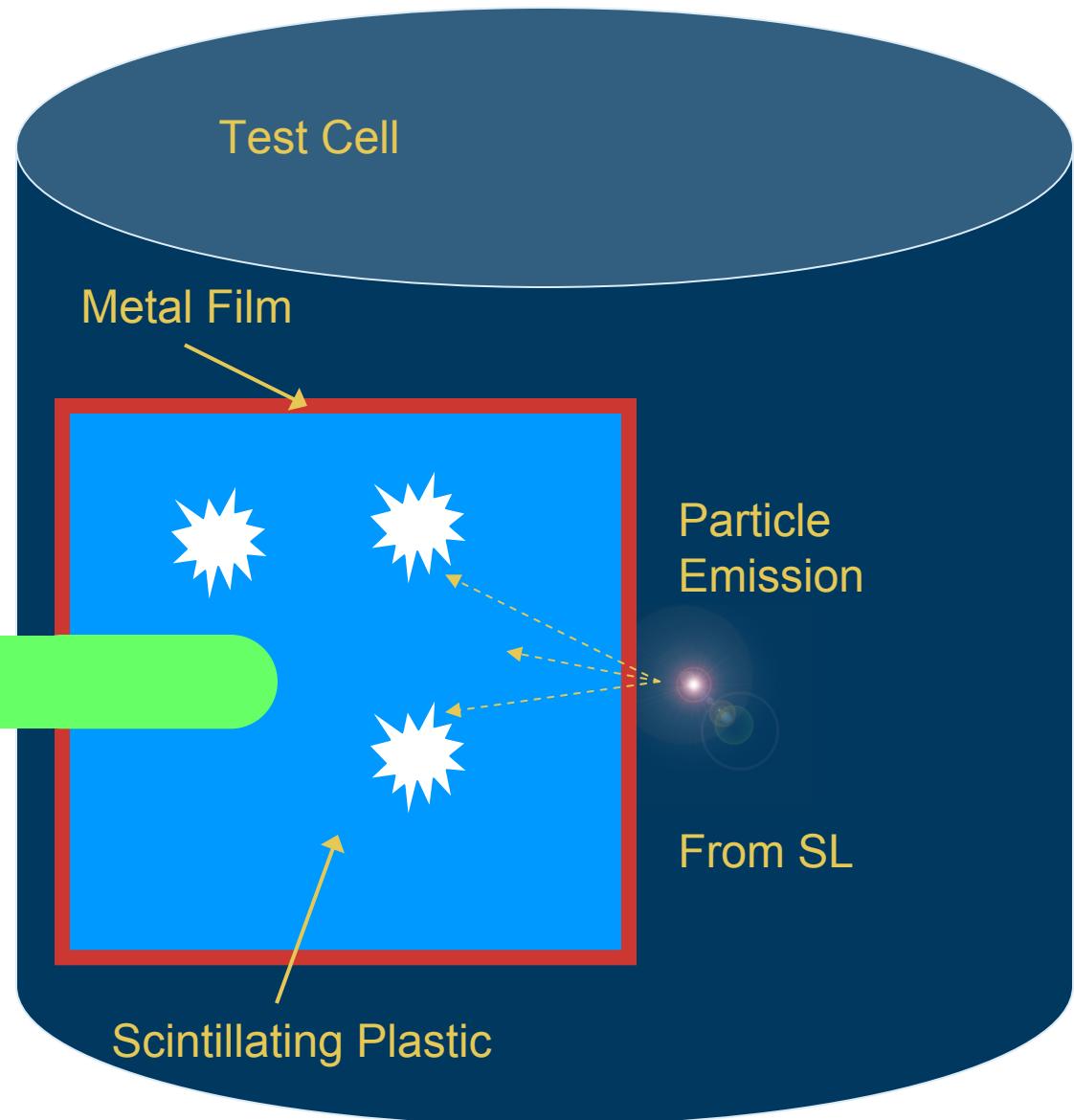


# Thin Film Coated Scintillating Detectors

- Fiber optic-based scintillator detector under development
- Particle emissions react with metal film
  - Results react with the scintillator

← Optical Fiber to PMT

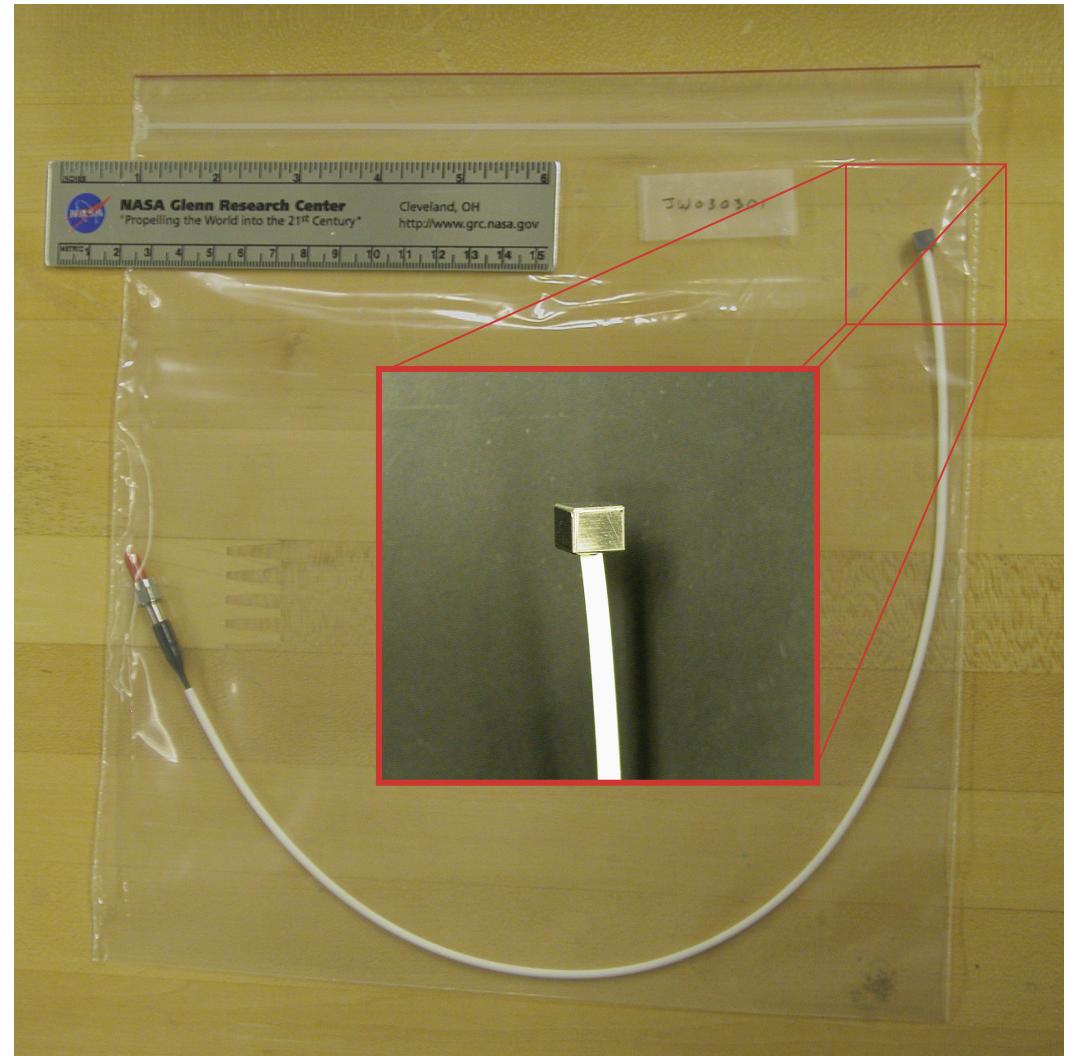
- Thin film coatings allow identification of processes that may be occurring





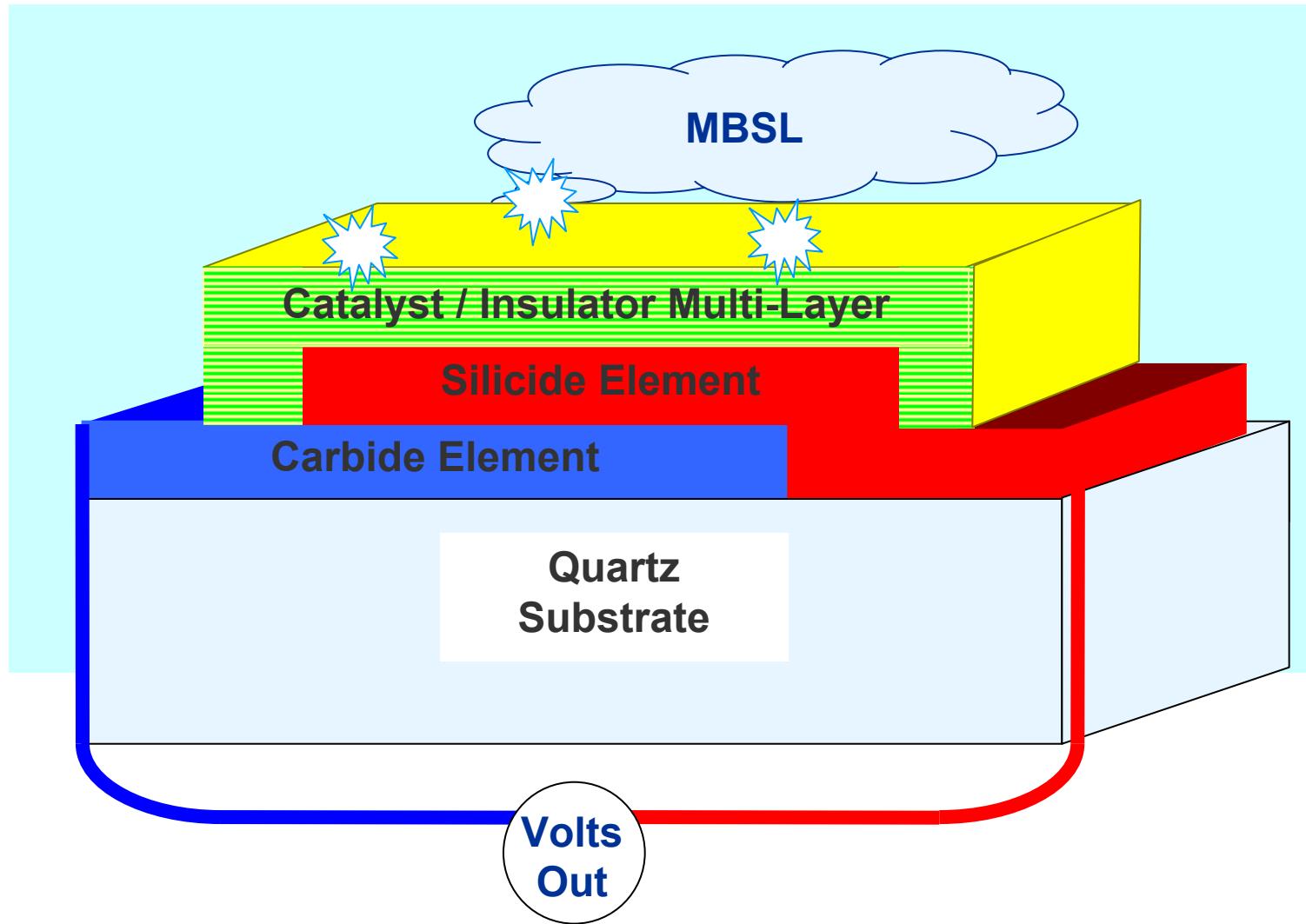
# Thin Film Coated Scintillating Detectors

- Prototype detectors fabricated
  - Rhodium for neutron detection
  - Copper as an attenuator,
  - Palladium as a possible catalyst based on thin film experiments
- Relative responses modeled using Monte Carlo program SRIM
- Very sensitive to external light noise
- Leveraging as detectors for Lunar Missions





# Energy Harvesting Concept

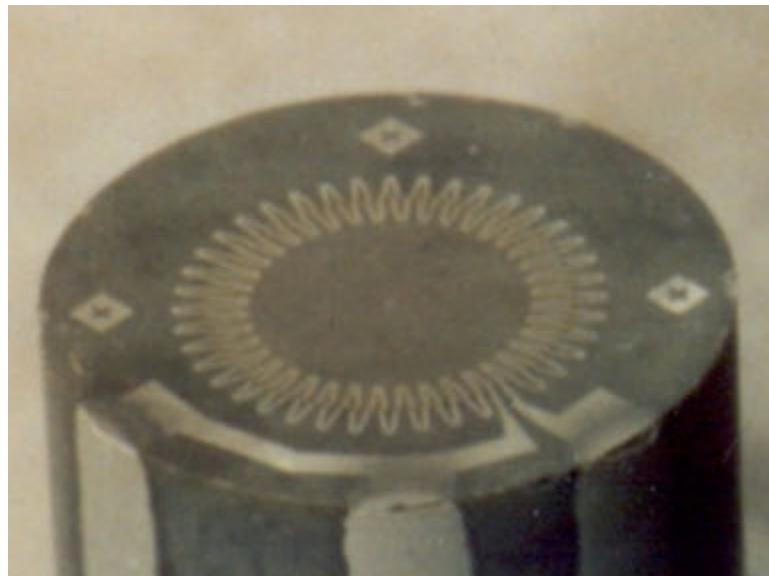


- Recent results in ceramic thin films suggest this concept is possible



# Energy Harvesting Concept

- Initial test of concept to use thin film thermopile for heat flux measurements
- Estimate of power generation:  
 $100\mu\text{V}/^\circ\text{C} \times \Delta T \Rightarrow 200 \text{ mV/junction}$   
 $200 \Omega/\text{junction} \Rightarrow 0.2 \text{ mWatts/junction}$   
50% efficiency  $\Rightarrow 0.1 \text{ mWatts/junction}$   
40 junctions  $\Rightarrow \underline{4 \text{ mWatts}}$
- Input electrical power of Sonicator  $\Rightarrow \underline{350 \text{ Watts}}$
- Improvements in thermoelectric materials are needed for energy harvesting to become practical



6 mm diameter, 40-pair thermopile thin film heat flux sensor



# Summary

- The high temperatures and pressures measured in sonoluminescence have generated claims and theories that predict a net gain of power resulting from atomic interactions.
  - Success has been recently reported in the mainstream academic press, and if practical, could revolutionize aerospace power systems.
- NASA Glenn Research Center (GRC) is developing instrumentation technologies for the support of the mission to pioneer the future in space exploration, scientific discovery, and aeronautics research.
- GRC is leveraging expertise in optical and physical instrumentation research to determine if the potential exists for energy harvesting from sonoluminescence.
- Multibubble sonoluminescence in water and glycerin has been generated at GRC for study.
- The modification of palladium thin films suggests the generation of high temperature from sonoluminescence in heavy water.
- Concepts for in situ radiation detection and energy harvesting are presented.



## Acknowledgments

- Alternate Fuel Foundation Technologies (AFFT) Subproject of the Low Emissions Alternative Power (LEAP) Project and the Breakthrough Propulsion Physics (BPP) Project at the NASA Glenn Research Center (GRC) for sponsoring this work.
- Nancy Rabel Hall of the Fluid Physics and Transport Branch at NASA GRC, for providing references and information on sonoluminescence and for reviewing this report.
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- Jonathan Wright of the University of Florida for this help in reviewing this work.



# The Researchers

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Research Engineers / Physicists

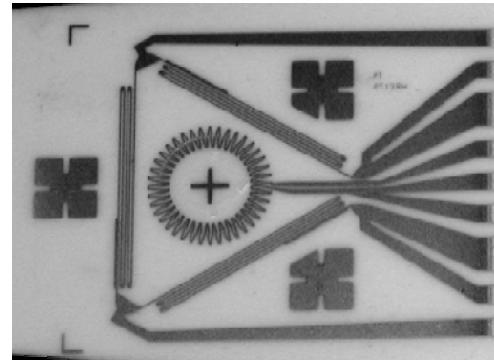
\*Thin Film Physical Sensors Instrumentation Research

†Nanophotonics and Optical Micromanipulation Research

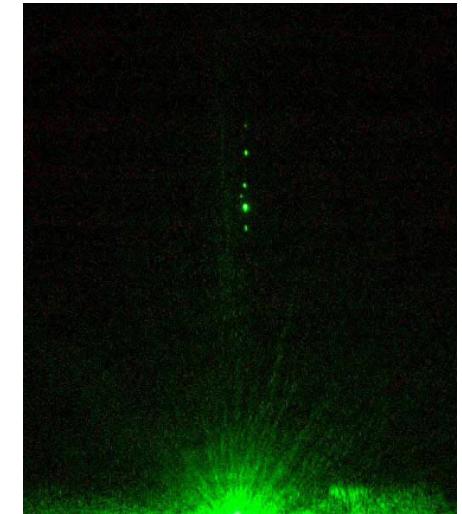
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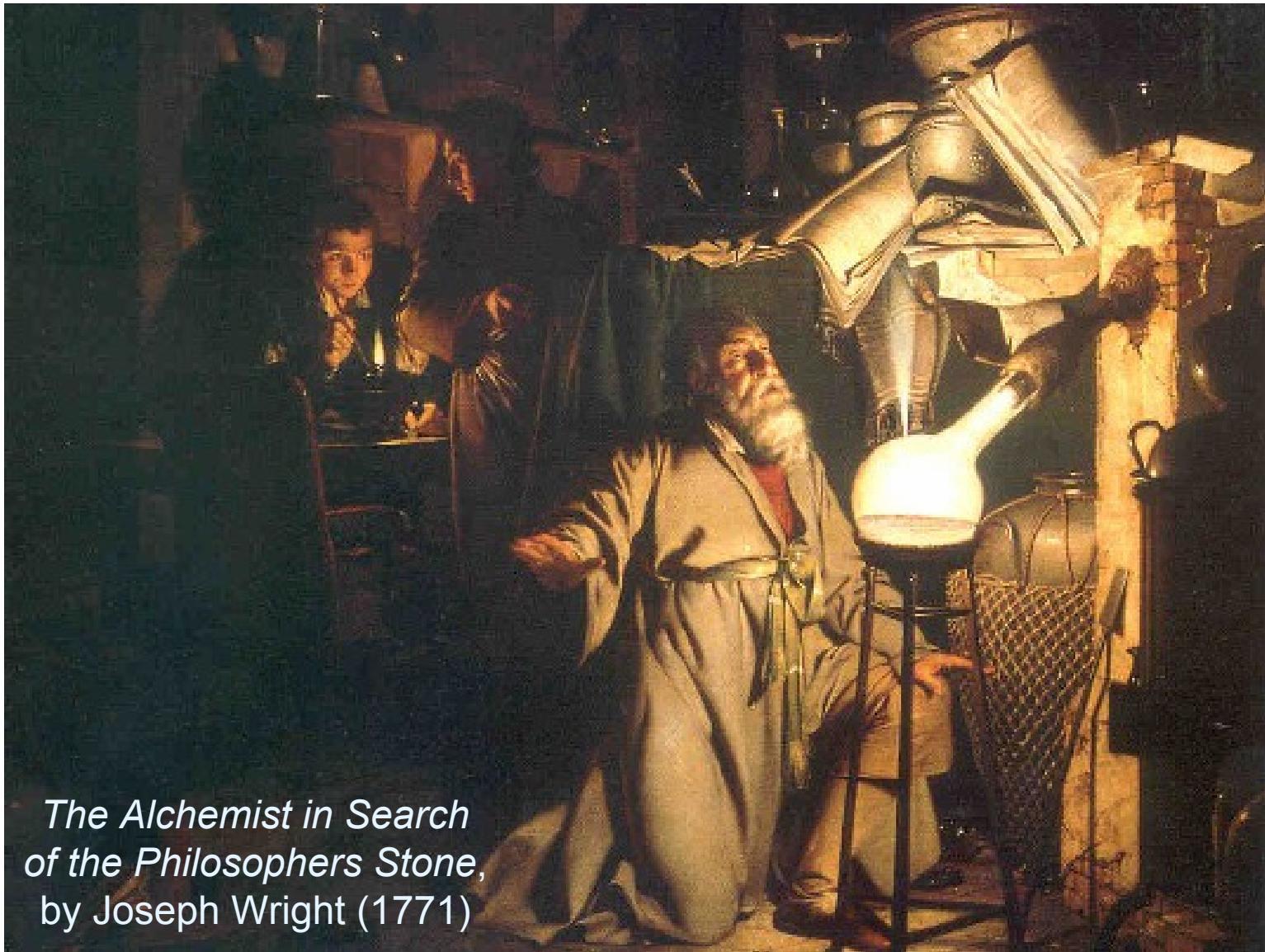


Thin Film Physical Sensors  
(G.C.Fralick & J.D.Wrbanek)



Optical Micromanipulation  
(S.Y.Wrbanek)

# Questions



*The Alchemist in Search  
of the Philosophers Stone,*  
by Joseph Wright (1771)